Appendix XIII

Market Impacts of Sea Level Rise on California Coasts

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1. Introduction

The potential effects of climate change on sea level are well established (Intergovernmental Panel on Climate Change [IPCC], 2001); a global temperature increase is likely to lead to both thermal expansion and the melting of polar ice caps, which contribute to the causes of sea level rise. Increases in sea level can affect individuals living in coastal and low-lying areas, inundate or impair wetland functions, and damage structures and property along the coast.

Research on the economic costs of sea level rise began in the 1980s, and progressed from early assessments that focused on total property at risk and protection costs in isolation to more recent efforts that incorporate both property values and protection costs (Yohe et al., 1996). Many of the published estimates focus on a very limited geographic scope or are national in scope. It has recently become clear that regional and subregional estimates of the economic cost of sea level rise are also needed to inform coordinated response and adaptation planning that is responsive to local conditions but recognizes that other relevant coastal policy choices may be made at the state level.

Recently, the California Coastal Commission examined the potential impacts of sea level rise along the state's coast. The commission identified significant portions of coast that were both extensively developed and low-lying or prone to erosion, including San Diego; Los Angeles; portions of San Luis Obispo, Monterey, and San Mateo; and the county of Humboldt. The commission also concluded that a mix of hard engineering (e.g., armoring) and soft engineering (e.g., beach nourishment) are likely to be employed, but that retreat from certain threatened areas is also an option (California Coastal Commission, 2001). The study, however, did not estimate the economic cost of these responses.

In this appendix, we assess the economic costs of sea level rise on a statewide basis for California. Our research focuses on effects on coastal structures.[1] To estimate the cost of sea level rise for California, we must consider three basic types of information: (1) areas that are vulnerable to inundation and when they become vulnerable; (2) the expected response from property owners and governments to the threat of inundation; and (3) the costs of plausible alternative responses. Our work relies on inundation mapping at sites modeled by Park et al. (1989) to estimate both the location and timing of inundation for four sea level rise scenarios: 33, 50, 67, and 100 cm by 2100.[2] The second of these (50 cm) closely approximates the expected

1. Note that, because of a lack of data and refined methods for estimating ecological effects, we do not examine the nonmarket economic impacts on wetlands.

2. Because the Park et al. (1989) model examines inundation patterns for California sites along the Pacific Ocean and San Francisco Bay area, we are unable to examine economic impacts along low-lying portions of the San Joaquin and Sacramento River.

rate of eustatic sea level rise established in IPCC (2001). Using the approach developed in Yohe et al. (1999), we model both the response and the cost of that response.

The economic model we use has three significant advantages over previous work. First, the model incorporates a site-specific decision-making process to assess whether it is more efficient to protect or abandon specific parcels of land, based on the costs of protection and the value of coastal structures that could be protected. Second, the model incorporates changes in property value over time, based on a representation of property value that relies on projections of gross domestic product (GDP) and population growth. Third, the model incorporates adaptive measures that landowners could take to mitigate impacts in the coastal zone, including ceasing investment in coastal properties in advance of inundation. Implicit in our characterization of adaptive measures is that adaptation is efficient; that is, we assume that individuals and the government protect only when the benefits of protection exceed the costs and that they act at the optimal moment. This is an optimistic assumption in this sector because much of the protective measures are “public adaptations” where there are many beneficiaries to an action. In practice, public adaptation will not likely be efficient (Mendelsohn, 2001). Although our estimates reflect the effects of inundation on coastal property and the costs of protection, they do not examine the protection of wetlands and the incremental storm damage caused by higher seas or changing storm intensities or frequencies.

This appendix includes three sections. First, we review our method for developing the estimates, including the selection and coding of data for new sites that, in aggregate, span a diverse set of conditions along the California coast. Second, we discuss site-specific and state-level results, including transient estimates of the timing of impacts for each region. Third, we discuss key uncertainties inherent in the approach and steps that might be taken to improve the estimates.

2. Methods

The Yohe et al. (1999) coastal structures model was used to estimate the regional economic impact of sea level rise in the United States. This model estimates the cost of rising sea level over time based on comparing the cost of protecting the coastline from inundation with the benefits of this protection; the benefits are characterized as protection of the opportunity cost of coastal property that would be abandoned if inundated. The true opportunity cost of abandoning coastal property should reflect the projected value of property at the future time of inundation as well as adaptive measures that would be taken to minimize property loss. The model, then, includes a representation of the future trajectory of property value for land and property threatened by inundation. In addition, the model incorporates two types of adaptive measures. First, the value of land lost to inundation is represented by the value of land located inland from the ocean. At the point of inundation, any price gradient associated with closer proximity to the ocean simply migrates inland, so that in most cases the real loss is best represented by the value of inland property. Second, if there is sufficient foresight, structure value should depreciate in the face of a growing risk of inundation. The depreciation serves to mitigate the losses associated with inundation. Full depreciation of structure value in anticipation of inundation is reflected in the "perfect foresight" model runs. Alternatively, an efficient process of depreciation could be hampered because there is not enough time, the risk communication is ineffective, risk perceptions are faulty, or because owners incorrectly expect that their land will be protected by public action. The "no foresight" model runs reflect no depreciation of the structure value, effectively bounding the impact of this adaptive measure.

The cost of coastal protection is based on two protection alternatives: hard structure armoring through the construction of dikes, seawalls, or bulkheads; and the placing of sand on the beach, often referred to as beach nourishment. The capital cost of hard structures of $935 per linear foot (in year 2000 dollars) was derived from a review of published studies; the value represents a central estimate from those studies. We model maintenance costs as a percentage of construction costs, again based on estimates reported in published studies. Four percent maintenance cost per year was chosen as the central estimate, but 10% was used for hard structures that might be built along coastline open directly to the ocean. The capital costs also reflect differences in the cost of building structures of different heights. For example, because the base of the required protective structure expands with its height, the structure necessary to protect property from a 1 m rise costs more than twice as much to construct as that necessary to protect from a 0.5 m rise. Finally, costs to nourish beaches were modeled using estimates of the requisite volume to nourish the full beach profile at a rate that matched the relative sea level rise, as well as regional estimates of the price of sand. Beach nourishment is assumed to be necessary starting immediately in 2010 (the first decadal estimate in our analysis), and is assumed to be effective as long as the sea level did not exceed 30.5 cm. Beyond that threshold, we assume that a hard structure constructed at the back of the beach is necessary to ensure protection of interior property.

The model simulates the protect/abandon decision as a dynamic cost and benefit comparison through time. Using a decadal time-step, the model calculates the net benefits of protection at the point when inundation is imminent. If net benefits are positive, the capital costs for a protective structure are incurred just before inundation, and maintenance costs are incurred for all subsequent years. If net benefits are negative, the land is abandoned and the opportunity costs of losing both the land and structure value are incurred. In theory, the dynamic nature of the model allows for situations where it might be reasonable to protect for some period of time but, as property values change over time, the benefit of protection could fall to a point where it is exceeded by the present value of the future stream of maintenance costs. In fact, the increasing trend in property values over time, associated mainly with increasing per capita income, ensures that once protection is calculated to have net benefits, continued protection remains the optimal course. The projected upward trend in development value reflects historical patterns of coastal development over the approximately three decade period prior to 1990, and is an important factor in accurately assessing future impacts in the coastal zone.

For this analysis, we used the model to generate regional sea level rise cost estimates for four scenarios of future eustatic sea level rise between the years 1990 and 2100: 33, 50, 67, and 100 cm. We assume a quadratic sea level rise scenario, which appears to best match the trajectory of sea level rise anticipated in IPCC (2001). For each of these four sea level rise scenarios, we generated two sets of economic impact estimates, one assuming perfect foresight and the other assuming no foresight.

Along with the rate of sea level rise (33, 50, 67, 100 cm) and the assumption about foresight, there are a host of other factors that influence the economic impact of sea level rise. Factors such as growth in state GDP, state population growth, and the discount rate are model inputs. The model also takes as input site-specific economic parameters such as the value of land and structures and the required length of protective structure necessary.

The model does not directly estimate regional impacts of sea level rise. Instead, the model generates site-specific cost estimates for a given set of inputs. We scale these site-specific model results to the full state using scaling procedures that make use of shoreline length data and sea level rise vulnerability estimates. As part of this project, we sought to add additional sites to be modeled using the procedure established in Yohe et al. (1999) and Neumann and Livesay (2001), for a total of seven California sites. The sites chosen were designed to yield a base of sample sites from which we could extrapolate effects for the full California coast — see Figure 1 for a map of the site locations. The four new sites chosen were Imperial Beach, which includes the area at the southern tip of San Diego Bay, with both open ocean and bayside frontage; Año Nuevo and the cliff site south of San Francisco; Palo Alto, in San Francisco Bay, which includes several low-lying residential areas; and Ferndale, along Humboldt Bay in northern California. At three of the four new sites, inundation mapping indicates that developed areas are vulnerable (the exception is Año Nuevo). In addition, the sites represent a diverse set of coastal topography and property value characteristics, and therefore a diverse set of coastal vulnerabilities to sea level rise, from which we can develop a statewide estimate of economic impact.

Under the four sea level rise scenarios and both foresight assumptions, we estimate the impact of sea level rise on these seven individual coastal sites. These seven sites, presented in Figure 1, were originally drawn from a larger set of sites chosen by Park et al. (1989),[3] to serve as a national sample for assessing the economic damage induced by sea level rise in the United States

3. The Park et al. (1989) site selection is described as follows: "Ninety-three sites were chosen, using an unbiased systematic sampling of U.S. Geological Survey topographical maps at a scale of 1:24,000. Starting with the easternmost quadrangle in Maine and restricting the choice to those maps that included some part of the coast, every 15th quadrangle was picked as the center of a site consisting of one to four quadrangles." As described in the text, Yohe (1990) interprets the results of the Park sampling to yield a roughly one/tenth sample of 30 minute cells, provided by the USGS. For the initial Yohe et al. (1990) work, and for subsequent economic modeling, a subsample of 30 sites was chosen from the 93 sites in the Park team's work.

Figure 1. Sea level rise candidate sites

(see Yohe, 1990). For modeling purposes, each site is divided into 500 m by 500 m grid cells.[4] Then, based on estimates of the timing of the inundation for each grid cell found in the Park et al. (1989) work, the model estimates the economic cost of sea level rise at each site. The timing of inundation proves to be crucial in our estimates of the current economic impact, because we assume that protective seawalls or dikes need not be built until just before inundation (although beach nourishment must begin immediately to be effective). The current value of the impact

4. At five sites, grid cells are 250 m by 250 m; this finer grid was used at Albion, Año Nuevo, Imperial Beach, Point Sal, and San Quentin.

estimates reflects discounting of costs back to the start of the study period. Reliance on the Park et al. (1989) sites provides more precise estimates of the timing of inundation, although it also limits our procedure to those sites modeled by the Park team.[5]

We aggregate the site-specific results up to the state level using a series of scaling factors. We base our scaling factors on sea level rise vulnerability estimates developed by the U.S. Geological Survey (USGS), including the coastal slope and coastal vulnerability index (CVI; see Thieler and Hammer-Klose, 2000). Specifically, we develop scale factors by comparing vulnerability estimates for the sites to average estimates for the state. USGS develops its CVI estimates based on a range of vulnerability factors (including tidal range, wave height, coastal slope, shoreline change, geomorphology, and historical rate of sea level rise). As a result, we feel that the CVI estimate provides the broadest indicator of vulnerability. Because CVI data are unavailable for most of the San Francisco Bay, we also apply a concurrent scaling approach for this area. We assume that the cost per mile for the Palo Alto site is equal to the average per-mile cost for the entire bay.

For comparison purposes, we also scale costs to the full state based solely on shoreline length of the sites versus the length for the entire state. This simplistic alternative makes the strong assumption that the seven sites we selected are representative of all California sites without any weighting to adjust for characteristics that should affect sea level rise vulnerability. For this scaling approach, we determine the average cost per mile for all seven sites (weighted by the sites' shoreline length) and multiply by the total state shoreline length. It is not likely, however, that these sites are a representative sample — we calculated these results only for comparison purposes.

For the seven sites used in this analysis, developed areas represent only a portion of the total land for which inundation is expected. As a result, we likely underestimated the amount of developed land at risk along the highly developed shoreline between Santa Monica and San Clemente — the Los Angeles area. Therefore, because this area will require significantly greater protection and beach nourishment than the seven sites, the vulnerability-based scaling approach likely underestimates protection costs. To address this potential bias, we also developed a second set of estimates using each of the four scaling methods discussed previously by estimating the cost of protecting the entire Los Angeles area with beach nourishment and protection costs. We use the beach nourishment and armoring costs for the 1.5 miles of developed shoreline in the Imperial Beach, California, site and apply these costs to the 87 mile Los Angeles area shoreline. This approach may overestimate costs, because it is not clear that all shoreline segments in the Los Angeles area will require beach nourishment and seawall protection. For example, we expect that commercial port facilities are already armored shorelines; the incremental cost of sea level rise is

5. The attachment contains further explanation of the procedures applied to model the inundation patterns and economic impacts for an example site.

to raise the maintenance cost of these armoring structures, and perhaps construction/rebuild costs as the armoring wears out, but clearly no beach nourishment is required. As a result, we believe that the "LA adjustment" procedure provides a better estimate than the basic scaling results, but may nonetheless overstate actual protection costs.

3. Results and Discussion

Table 1 reports the economic cost of sea level rise under all four scenarios at two discount rates (3% and 5%) for each of the seven individual sites and for the state as a whole using several differing aggregation schemes. The values presented in this table show that the total estimated economic impact of a 100 cm sea level rise in California varies from $148 million (based on CVI scaling and a 5% discount rate) to $635 million (based on shore length scaling, a 3% discount rate, and the LA adjustment). Comparison across scenarios reveals that the estimates follow the expected pattern; the expected economic impact of sea level rise increases sharply with steeper sea level rise trajectories, as illustrated in Figure 2.

The estimates presented in Table 1 and Figure 2 suggest that the scaling procedure has a major effect on our results, particularly at higher levels of sea level rise. The method of extending results to the Los Angeles region, in particular, has a major effect on our results, highlighting the problem noted earlier in estimating costs for this region in the absence of inundation mapping that reflects both the spatial distribution and timing of sea level rise vulnerabilities. For example, in the 100 cm scenario, using the LA adjustment procedure on the CVI scaled results increases the estimate by 47%, from $407 million without the adjustment to $597 million with the adjustment.

Note that the results presented in Table 1 reflect a no foresight assumption — foresight has only a modest effect on the results in California because a protection response is implied for all but the San Quentin site. In our model, foresight has no effect on the marginal protection costs, affecting only the costs of abandonment. The almost uniform finding at these California sites of protection strategies over retreat in response to sea level rise stands in contrast to our prior national results, where retreat or partial retreat was an efficient response at approximately one-third of the sample sites nationwide (Yohe et al., 1999). Our finding that protection is an economically efficient response at most developed sites in California reflects the relatively high economic values for California coastal properties. As a result, the types of adaptive measures we model (depreciation of structures before inundation and the efficient transfer of amenities associated with coastal frontage to the next inland properties) are likely to have little impact on the economic cost of sea level rise for coastal structures in California.

Table 1. Present value of cost estimates for coastal protection strategy from 2000-2100 (millions of year 2000 dollars)

Site estimates	**33 cm SLR scenario**		**50 cm SLR scenario**		**67 cm SLR scenario**		**100 cm SLR scenario**	
Site name	**3% dr**	**5% dr**	**3% dr**	**5% dr**	**3% dr**	**5% dr**	**3% dr**	**5% dr**
Albion, CA	Zero inundation							
Año Nuevo, CA	Zero inundation							
Ferndale, CA	0.127	0.026	0.741	0.187	1.757	0.513	4.922	1.496
Imperial Beach, CA[a]	0.329	0.051	0.626	0.205	1.178	0.344	3.455	0.884
Palo Alto, CA[b]	2.484	1.125	8.015	3.832	14.589	7.064	34.744	16.715
— Newark	1.882	0.877	5.986	2.933	10.676	5.257	25.288	12.368
— Redwood Shores	0.604	0.248	2.029	0.899	3.914	1.807	9.456	4.347
Point Sal, CA	Zero inundation							
San Quentin, CA	0.278	0.122	0.994	0.409	2.059	0.849	5.509	2.176
Full state estimates								
Scaling approach								
CVI	$25	$10	$82	$36	$160	$67	$407	$168
Slope	$22	$9	$74	$31	$142	$60	$358	$148
Shore length	$27	$10	$90	$37	$175	$74	$445	$182
CVI w/ LA adjustment	$47	$12	$117	$46	$224	$87	$597	$216
Slope w/ LA adjustment	$41	$11	$108	$42	$208	$80	$551	$198
Shore length w/ LA adjustment	$46	$14	$123	$49	$238	$92	$635	$229

Notes:
All estimates assume a rate of 4% for variable costs of protection, unless otherwise specified. SLR is sea level rise; dr is discount rate.
a. An open ocean site that employs a beach nourishment strategy and a 10% variable protection cost.
b. Estimates are the sum of results for subsites analyzed at that location.

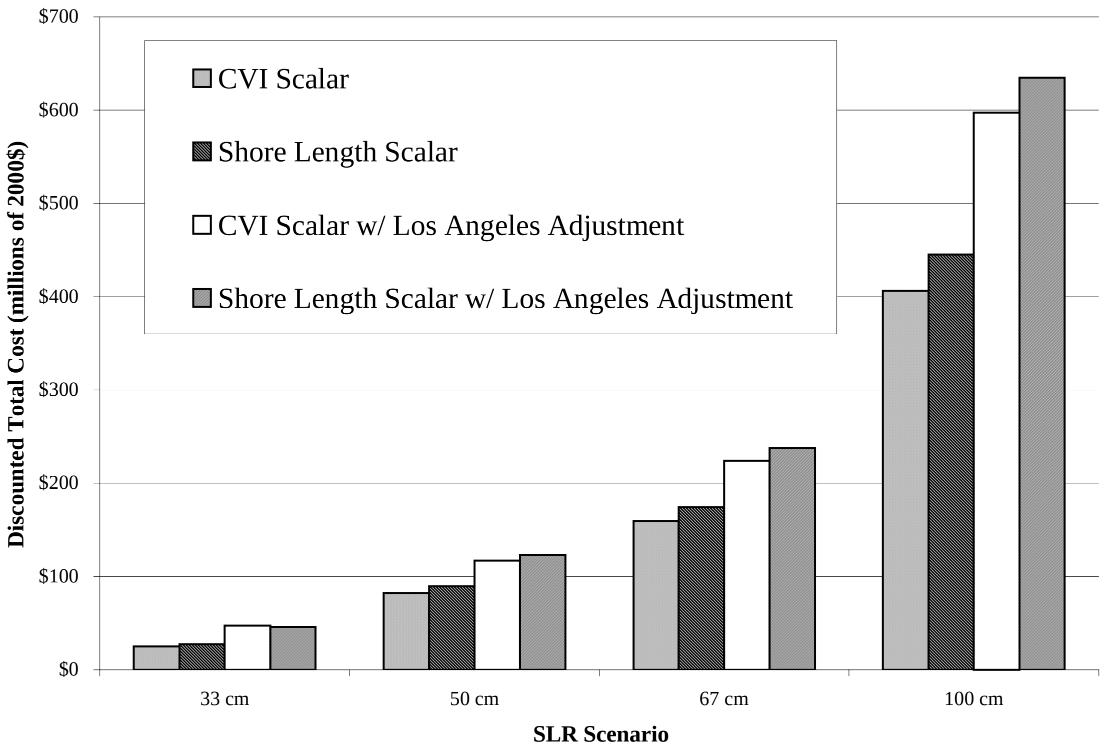

Figure 2. California's economic cost of sea level rise

Our findings suggest that land use planning in the coastal zone can play an important role in adapting to sea level rise, resulting in lessened impacts. The modeled inundation pattern at our sample sites is largely focused on (1) wetland sites, for which we were unable to obtain property values but which we can assume have positive ecological value to society, and (2) relatively densely developed or at least highly valuable properties. Where relatively densely developed sites are vulnerable, our modeling suggests that protection is the dominant response, but our technique does not reflect the lost economic value of inundated wetlands. Forward-looking land-use planning around wetland areas, however, may ensure that dry land just landward of vulnerable wetlands is protected from development, allowing for retreat of wetlands and maintenance of at least a portion of the ecological value of wetlands. In addition, land use planning at less densely developed or currently undeveloped sites, including the large portion of California's coastal land that is currently used for military purposes but may be redeveloped in the future, may help to mitigate future losses by steering future development toward sites that are less vulnerable to sea level rise.

Examining the transient costs offers insight into the timing of impacts. Figures 3 and 4 and Table 2 illustrate the transient costs of sea level rise using CVI scaling under all four scenarios, calculated with and without the LA adjustment, respectively. The increasing trend in sea level rise (in current-year costs) reflects the "just-in-time" need for capital investment in protection, which triggers increases in cost through the middle of the 21st century, beginning in about 2040. Costs up to 2040 largely represent the ongoing cost of beach nourishment, which begin in 1990 and grow as increasing volumes of sand are needed to maintain a constant beach profile. The lump sum investments for hard structures that begin in 2040 are followed by ongoing expenditures required for operation and maintenance, as well as ongoing beach nourishment at open ocean sites. In prior work, the trajectory of costs was highly dependent on the pattern of inundation at just a few sites. Our current results reflect a greater number of sites, yielding a smoother trajectory over time, although the results are still largely dependent on the results for the Imperial Beach site, which drives results for most of the Southern California region. These results suggest that capital and operating costs for hard structures and beach nourishment could steadily climb to approximately $1.0 billion (in year 2000 dollars) per decade by 2100.

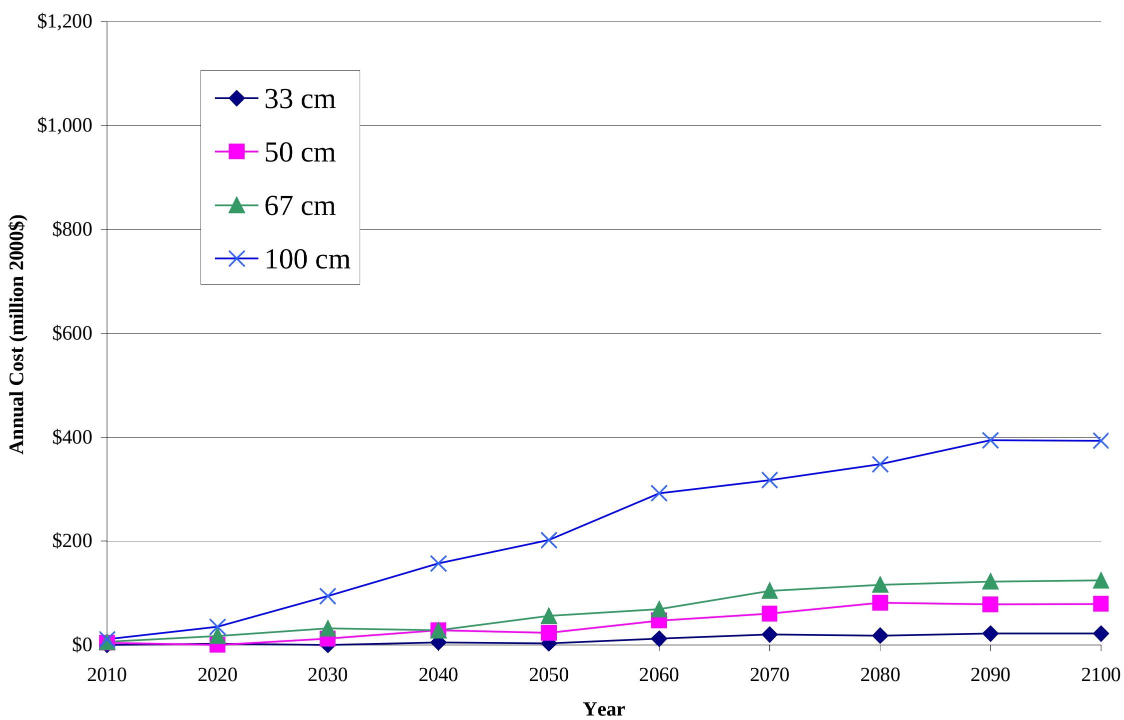

Figure 3. California transient costs for sea level rise without Los Angeles adjustment

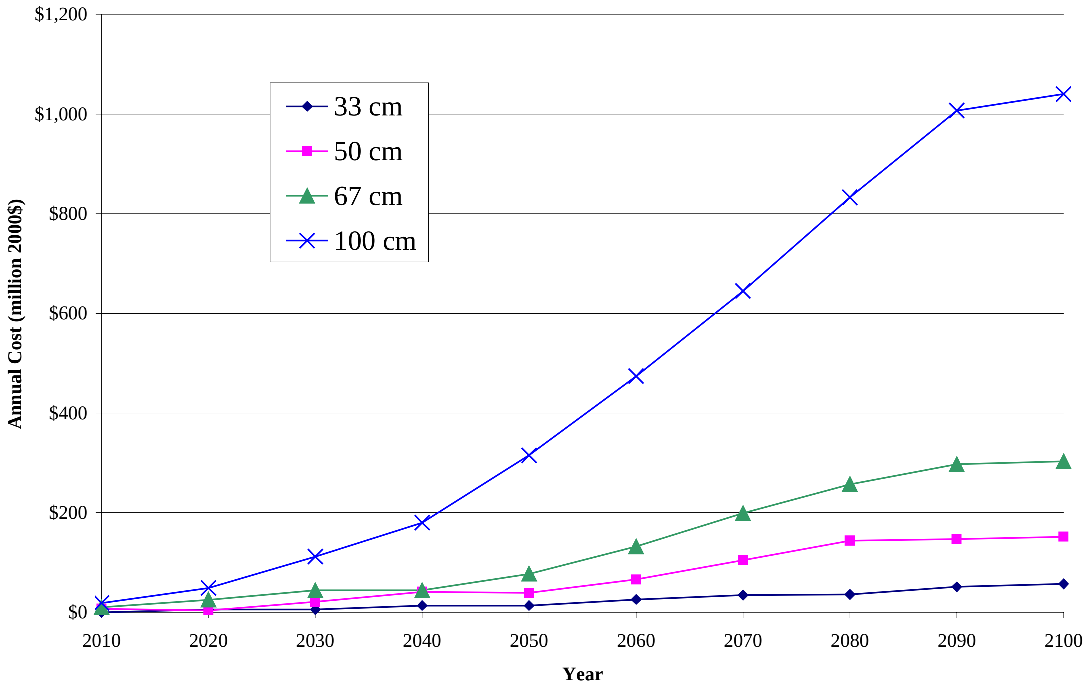

Figure 4. California transient costs for sea level rise with Los Angeles adjustment

Table 2. California decadal transient costs (millions of undiscounted 2000 dollars)

	CVI					CVI with LA adjustment			
Year	**33 cm**	**50 cm**	**67 cm**	**100 cm**	**Year**	**33 cm**	**50 cm**	**67 cm**	**100 cm**
2010	0	4	6	11	2010	0	7	10	19
2020	2	0	17	35	2020	6	4	25	49
2030	0	12	32	94	2030	6	21	44	112
2040	5	28	28	157	2040	14	41	44	180
2050	3	23	56	202	2050	14	39	77	315
2060	12	47	69	292	2060	26	66	132	474
2070	20	60	104	317	2070	35	105	199	645
2080	18	81	116	348	2080	36	144	257	833
2090	22	78	122	394	2090	51	147	297	1,007
2100	22	79	124	393	2100	57	152	303	1,040

CVI Scaling Approach Results

Region	33cm	50cm	67cm	100cm
North Coast	$2	$8	$16	$46
San Francisco Bay	$13	$43	$79	$189
Mid Coast	$2	$6	$12	$33
South Coast	$3-$18	$10-$37	$21-$73	$57-$210
TOTAL	$20-$35	$66-$94	$128-$180	$326-$479

Shore Length Scaling Approach Results

Region	33cm	50cm	67cm	100cm
North Coast	$3	$10	$20	$56
San Francisco Bay	$14	$44	$80	$190
Mid Coast	$2	$7	$15	$41
South Coast	$4-$19	$12-$39	$25-$77	$70-$221
TOTAL	$22-$37	$72-$99	$140-$191	$357-$509

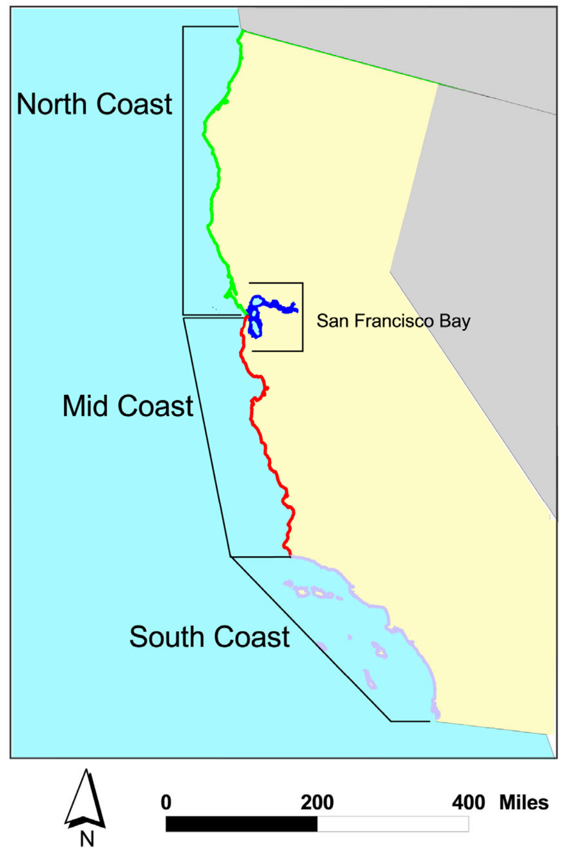

Figure 5. California's regional economic cost of sea level rise

Figure 5 illustrates the geographic distribution of costs within California. As shown, the San Francisco Bay and South Coast (which includes the Los Angeles area) incur the majority of costs. In contrast, the less densely developed and more sheltered coast along the northern and middle portion of the state account for less than 25% of the total costs. The low estimate for the South Coast area reflects the basic scaling approaches; the high estimate reflects the basic scaling approach with the LA adjustment.

Our work provides a first approximation of the economic implications of sea level rise for coastal structures in California, including estimates of costs through time. The extension of previous work to reflect the results at a greater number of sample sites improves those earlier estimates, but limitations in the readily available inundation data result in statewide estimates that remain uncertain to within roughly a factor of two. To the extent that policy development applications at the state level require more precise estimates, additional effort should be devoted to understanding the expected inundation pattern in the Los Angeles area. Our adjusted estimates provide a first approximation of protection costs for this region, but do not yet reflect careful modeling of the inundation pattern or site-specific considerations of the response strategies for commercial/port versus urban/residential versus lower density residential development. Our estimates with and without the LA adjustment likely bracket the estimates that could result from more careful modeling of response options that vary by land use type, because the adjustment assumes that the entire LA region adopts the most expensive response option, beach nourishment followed by seawall construction at the back of the nourished beach. In addition, the current estimates do not reflect potential impacts of sea level rise in some estuarine or brackish areas of San Francisco Bay, particularly the San Joaquin Delta, which are currently vulnerable to riparian flooding and may face an increased risk of flooding as the bay level rises.

Three other refinements may also yield interesting insights that can guide efforts to increase California's adaptive capacity to sea level rise. First, as outlined above, analysis of the economic value of coastal wetlands, the vulnerability of wetlands to sea level rise, and the costs of setting aside areas landward of these wetlands as limited development areas to allow retreat of wetlands might provide direction for state and private land conservation areas. Efforts in this direction should include systematic analyses of the major uncertainties in quantifying the economic value of coastal wetlands as well as estimating the viability and migration capacity of important wetland functions in the face of rising seas.

Second, ongoing work to estimate future land use patterns in California could serve as the basis for incorporating a dynamic land use input to the economic model employed here. The greatest value of such work would be at currently undeveloped or less-developed sites, and potentially at currently urban sites where the possibility of economic decline or adaptive redevelopment is evident. In addition, the possibility of sea level rise vulnerabilities affecting private and public investment in coastal infrastructure suggests that projections of future land use in the coastal zone could be substantially influenced by processes of learning and adaptive responses to this risk. By integrating this modeling approach in a GIS framework, users could examine the economic impacts of development and shoreline armoring decisions. Such a framework would facilitate the use of finer resolution data and local-level analyses.

Third, erosion and storms also affect California's coastal area by damaging structures and in some cases leading to earlier protection decisions. For example, El Niño events have damaged the state's energy infrastructure and cliffside homes. Thus, for the extensive cliff areas located along California's northern coastline, it would be useful to identify the rate of erosion and the resulting cost of either stabilizing the cliffs or of allowing structures to fall into the ocean. In the case of storm-related flooding, we could integrate estimates of the frequency of storm damage to identify the extent to which property owners might construct protective structures before inundation by sea level rise. The timing of such responses is a key factor in estimating the present value of coastal planning decisions.

The focus on adaptation in the coastal zone is consistent with scientific results that suggest we are already committed to a substantial increase in the sea level through roughly the middle of the 21st century. If actions can be taken to limit temperature increases and sea level rise, perhaps some of the larger costs that we project will be incurred in the latter half of the century may be mitigated. Regardless of the efficacy of those actions, however, refinements and extensions of our approach such as those discussed here can guide local-level land use decisions that have the potential to substantially affect California's adaptive capacity in the coastal zone.

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Appendix XIII — Attachment

Detailed Explanation of the Modeling Approach

In this attachment, we provide additional detail on the modeling employed in the analysis by illustrating the approach for one site — the Newark area of Palo Alto. We provide information on the collection of site profile data, including inundation patterns and real estate values, as well as the steps employed in running the coastal structures model.

Coastal inundation modeling

We estimate the land areas expected to be inundated under the various sea level rise scenarios using the SLAMM model developed by Park et al. (1989). Using available data on land cover and elevation, the SLAMM model simulates the inundation of both dry lands and wetlands as well as the conversion of dry lands to wetlands under long-term sea level rise. When running the SLAMM model, we identify decadal-level changes in the amount of dry land. Specifically, for the Palo Alto study, we identify 20 grid cells (each 500 meter by 500 meter in size) that become inundated or converted to wetlands under a 100 cm sea level rise scenario. This translates to more than 1200 acres or 2 square miles.

Additionally, we identify the year when each grid cell becomes inundated. The year of inundation is important for estimating how far into the future property owners can wait before protecting or abandoning their land, which has a significant impact on the present value of the response costs. Figure A.1 illustrates the land lost to sea level rise between 1983 and 2100 (the beginning and end years of the model) under a 100 cm rise in sea level in the Palo Alto study site. The white areas represent wetlands and the magenta areas represent dry lands. As shown, the model identifies all wetlands as becoming inundated. Because it is difficult to visualize the interface between water and land, we have added an approximate shoreline to the map for illustrative purposes only. Table A.1 identifies the number of dry-land grid cells that would be inundated in each decade.

Real estate values

Next, for each area that SLAMM predicts will be inundated by sea level rise, we obtain data on the current value of the property. By examining the location of these inundated cells on topographic maps, we are able to identify specific communities affected by sea level rise. As described in the main body of this appendix, we obtain average area property values that capture the economic cost to society from the loss of property. For this study, we obtained estimates of average property values from available on-line sources of property transaction prices. The on-line residential and commercial real estate site used for this location is http://Loopnet.com.

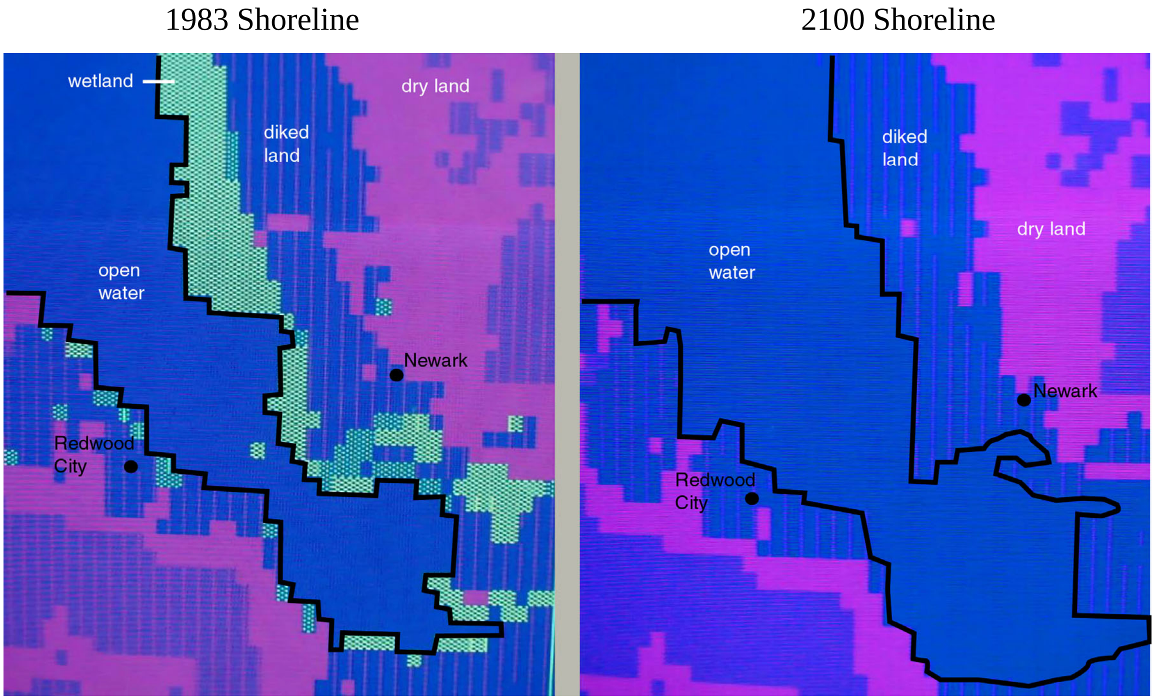

Figure A.1. SLAMM2 inundation model results for Palo Alto, California, under a 100 cm sea level rise

Table A.1. Estimated inundation modeling under 100 cm sea level rise for Newark portion of Palo Alto using SLAMM

Decade	Grid cells inundated
2000	5
2010	4
2020	2
2030	3
2040	3
2050	0
2060	3
2070	0
2080	0
2090	0
2100	0

Note: Each grid cell is 500 m by 500 m.

Within the Palo Alto area, we opted to identify separate property value estimates for two significantly different communities (Newark and Redwood Shores). For the Newark portion of Palo Alto, we identify a per-acre average property value of $2.8 million.

Protection costs

Using these data, we create a site profile specific to the Newark portion of the Palo Alto site. This site profile provides the model with the inputs described previously, as well as the estimated capital and annual cost to armor the shoreline. For the Palo Alto sites, we assume a capital cost of $935 per linear foot (in 2000 dollars), which equates to approximately $1.5 million to armor one grid cell (e.g., 500 m * 3.28 ft/m * $935). We also use the profile to identify annual maintenance costs to maintain protective structures, which we estimate to be 4% for Palo Alto (as noted in the main text of this appendix, 10% is used for open ocean sites).

Property value changes over time

The site profile also provides the model with scalars to estimate future property values. Our previous research identified a model of future property values developed by Federal Reserve researchers that relies on projected changes in national gross domestic product, construction costs, and household income (see Yohe et al., 1999 for more details). In this application, we apply a national GDP estimate, rather than California-specific estimates, because we are uncertain whether the national model can be reliably applied using subnational data. The effect of this assumption is likely to be trivial, if not completely inconsequential, because at all California sites we modeled the decision is made to protect properties. For this reason, the impact estimates are driven by protection costs, not property values. Although it is possible that using California-specific projections, if they were available, might alter projection decisions, we believe that it is highly unlikely that California coastal properties in our model would increase in value at a rate slower than in the remainder of the country.

Modeling parameter choices

For each model run, we can also select the sea level rise scenario (e.g., 33, 50, 67, or 100 cm rise), whether to assume that the rise takes place in a linear or quadratic fashion, and whether to assume that property owners will anticipate the loss of their property starting 30 years before inundation and adapt their property investment and upkeep decisions accordingly. In addition, we can override the default GDP and property value price change factors if desired. As stated previously, the default GDP and property value price change factors were used in the runs reported here.

The model applies these inputs to estimate the protection costs versus potential lost property value for each decade in which a grid cell becomes inundated. If the protection costs are less than the property value, the model assumes that protection will be applied. This yields impact estimates that reflect construction costs in the decade of inundation as well as structure maintenance costs in the years that follow. Although not the case for Palo Alto, or any of the other California sites we modeled, if protection costs exceed the value of the property, the model assumes that the land is abandoned and the cost to society is equal to the lost property value. Table A.2 illustrates the decadal cost estimates for Palo Alto's Newark area.

Table A.2. Estimated decadal sea level rise costs for the Newark portion of Palo Alto, California (millions of undiscounted 2000 dollars)

	Sea level rise scenario			
Decade	**33 cm**	**50 cm**	**67 cm**	**100 cm**
2000	0.8	2.2	3.4	7.6
2010	0.4	2.7	4.3	9.7
2020	1.1	1.9	4.3	9.7
2030	0.8	2.7	5.7	12.8
2040	1.1	3.5	4.7	15.1
2050	0.9	3.0	6.8	13.1
2060	1.5	4.2	5.8	17.7
2070	1.8	3.6	7.8	15.7
2080	1.5	4.7	7.0	15.9
2090	1.5	4.3	7.0	16.1
2100	1.5	4.5	7.2	16.2
Total	12.7	37.3	63.8	149.9